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TRANSPARENCY OF THE ATMOSPHERE AT THE MOUNT WILSON SOLAR OBSERVATORY.

By J. van der Bilt.

During a visit to the Mount Wilson Solar Observatory in the fall of 1916 I had the opportunity of making a few observations relating to the transparency of the atmosphere at that station. The presentation of the results in a quantitative form seemed to me important in as much as such material, when compared with that from other existing or projected stations, would be capable of emphasizing the advantage of a mountain site for astronomical work or of giving some guidance in the choice of such a site. As a matter of fact, the transparency of the air may be considered a function not merely of the altitude but also of several local atmospheric conditions, especially the presence of smoke or fine dust in high regions of the atmosphere.

The observations were suggested to me partly by a paper on the visibility of stars in daylight, read by Professor Russell at the Swarthmore meeting of the American Astronomical Society, and partly by the fact that systematic visual observations on this subject seem never to have been published. The detailed tests of observing conditions on Mount Wilson, made by Professor Hussey,[1] apply merely to the *seeing,* and the results on the transparency of the day-sky obtained by Abbot and of the night-sky by Barnard do not render out of place the naked-eye observations presented here.

The observations can be divided into three groups, viz., those made (1) on the visibility of stars and planets in daylight; (2) on the visibility of a thin moon-crescent; and (3) on the limiting stellar magnitude on a moonless night. All these observations were made under only moderately good conditions; they were begun after the most favorable season was over and were made whenever it suited the observer best, not when circumstances were believed most suitable for first-rate results. The conclusions to which they have led, therefore, cannot be considered to exaggerate matters; on the contrary, they may give in several ways a too conservative statement of the facts.[2]

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[1] *Carnegie Institution of Washington Year Book* **2**, 71 (1903).

THE VISIBILITY OF STARS AND PLANETS IN DAYLIGHT.

The observations on stars were all made at sunrise, because these give more accurate results than those made at sunset. The time of disappearance of a star can be noted with an accuracy of one or two minutes, but the determination of the exact time when a star becomes visible is liable to a much greater error. The method of observation consisted in pointing a small telescope at the star or planet, so as to enable the observer to look in the right direction, and in noting every two minutes whether with the unaided eye the object was still visible. To obtain the time of disappearance, one minute was added to that of the last notation of visibility. For *Jupiter* only two observations of the time of disappearance could be obtained before it became an evening star, and the appearance instead of the disappearance had to be observed. To obtain the time of appearance one minute was subtracted from that of the first notation of visibility. The fact that the morning observations give practically the same results as the later evening observations prove that in this case the difference in accuracy cannot be very great.

The detailed observations are given in Table I. The second column gives the magnitude, taken from the American Ephemeris, the third column the extinction correction taken from Müller's table (reduced to the altitude of Mount Wilson), the fourth the apparent stellar magnitude of each object, and the following two the hour-angle and altitude. The phenomenon is indicated by *d* (disappearance) or *a* (appearance).

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[2] The author's eyes are very little, if any, better than the average. At Utrecht the faintest stars visible to him under average conditions are approximately of magnitude 5.8.

TABLE I

Visibility of Planets and Stars in Daylight

Object	Mag.	Ext. Corr.	Corr. Mag.	Hour Angle	Altitude	Phenomenon	Date 1916 M. T. 120th Mer.	Sun's App. Alt.
Jupiter	—2.4	$0^{M}.2$	—2.2	$+4^{h}21^{m}$	26°.8	d	Sept. 21 $18^{h}26^{m}$	+ 7°.1
"	"	"	"	+4 38	23 .3	"	" 24 18 30	+ 7 .5
"	"	0 .7	—1.7	—5 32	10 .7	a	Nov. 15 4 33	+ 3 .8
"	"	0 .5	—1.9	—5 18	13 .8	"	" 18 4 34	+ 3 .2
"	"	0 .4	—2.0	—5 3	16 .8	"	" 24 4 24	+ 4 .5
"	—2.3	0 .2	—2.1	—4 28	23 .9	"	Dec. 4 4 16	+ 5 .4
"	"	"	"	—4 29	23 .6	"	" 9 3 55	+ 9 .7
"	"	"	"	—4 33	22 .8	"	" 10 3 47	+10 .4
"	"	"	"	—4 15	26 .5	"	" 13 3 52	+ 9 .7
"	—2.2	0 .1	"	—4 12	27 .1	"	" 15 3 47	+10 .4
"	"	"	"	—4 9	27 .7	"	" 18 3 38	+12 .1
Sirius	—1.6	"	—1.5	—0 33	38 .6	d	Sept. 24 17 52	0 .0
"	"	"	"	+1 30	35 .0	"	Oct. 20 18 14	0 .0
"	"	0 .3	—1.3	+3 7	22 .5	"	Nov. 10 18 27	— 0 .6
"	"	0 .4	—1.2	+3 53	15 .0	"	" 20 18 33	— 1 .4
Arcturus	0.2	0 .1	0.3	—3 33	40 .9	"	" 23 18 27	— 3 .0
"	"		0.2	—1 36	64 .2	"	Dec. 15 18 57	— 0 .6
"	"		0.2	—1 9	68 .8	"	" 22 18 56	— 1 .5
Saturn	0.5		0.5	—2 11	58 .0	"	Sept. 24 17 36	— 3 .2
"	0.4		0.4	—0 10	75 .8	"	Oct. 20 18 01	— 2 .6
"	0.3		0.3	+1 31	65 .4	"	Nov. 10 18 21	— 1 .9
"	0.3		0.3	+2 19	56 .3	"	" 20 18 29	— 2 .2
"	0.1	0 .1	0.2	+3 56	36 .5	"	Dec. 10 18 45	— 2 .4
Procyon	0.5		0.5	+0 21	60 .8	"	Oct. 20 17 58	— 3 .4
"	"	0 .1	0.6	+2 51	41 .1	"	Nov. 20 18 25	— 2 .9
"	"	0 .3	0.8	+4 23	23 .1	"	Dec. 10 18 39	— 3 .5
Pollux	1.2		1.2	+1 52	65 .4	"	Nov. 10 18 11	— 3 .8
Regulus	1.3		1.3	+2 11	53 .1	"	Dec. 15 18 36	— 4 .6
"	"		"	+2 46	46 .5	"	" 22 18 43	— 4 .0
Castor	1.6		1.6	+2 0	64 .8	"	Nov. 10 18 07	— 4 .6
"	"		"	+2 45	55 .6	"	" 20 18 13	— 5 .2
"	"	0 .1	1.7	+4 22	36 .1	"	Dec. 10 18 32	— 4 .8
Denebola	2.2		2.2	+0 59	66 .7	"	" 22 18 37	— 5 .0

Outside the plan of these observations, on account of its nearness to the Sun, is an observation of *Mercury* near its western elongation. It was visible on October 20 until 17^h 47^m (M. T. 120th Meridian), the Sun at that time being 5°.5 below the horizon.

It can hardly be doubted that differences in transparency are chiefly responsible for the differences found for the same object on different days. Most striking is the late visibility of *Jupiter* on the four dates from November 15 to December 4, inclusive. Meanwhile it must not be overlooked that an error of 2^m in the noted time means a difference of about 0°.4 in the Sun's altitude. It is of interest to note that neither the theoretical decrease of $0^M.2$ in the apparent brightness of *Jupiter,* nor the increase of $0^M.4$ in that of *Saturn* is shown by the observations.

THE VISIBILITY OF THE THIN MOON-CRESCENT.

Experience has shown that the visibility of the Moon-crescent is a very sensitive test of the transparency of the atmosphere, but one that unfortunately can be made only on two days each month. Two days before or after the time of new moon, the crescent is already so easily visible that no telescope is needed to find it, even with the Sun in the meridian. It was noted, for instance, as very distinctly visible on October 23, 22^h 0^m and October 28, 1^h 30^m, times which were, respectively, $50^h.6$ and $48^h.9$ from new moon, the phase-angles being about 157° and 158°. As soon as the phase-angle exceeds 160° the visibility begins to depend to a large extent on the transparency of the atmosphere; and to make the test of value it should be necessary to locate the crescent with a telescope. The observations are given in Table II. Even allowing for the fact that the decreased distances Earth-Sun and Moon-Earth favored the observation of November 22,

TABLE II

VISIBILITY OF THE MOON-CRESCENT

Date, 1916	Moon-crescent last seen	Age	Phase angle	Sun's altitude
Sept. 24	17^h52^m	$-41^h.7$	160°	+ 1°.4
Nov. 22	22^h30^m	-38 .3	161	+33 .0
Dec. 22	18^h47^m	-29 .7	164	− 1 .7

the visibility of a Moon-crescent of about 38 hours with the Sun nearly in the meridian reveals a remarkable condition of transparency. It is hardly necessary to say that in such observations the Moon's stellar magnitude cannot be considered.

THE LIMITING STELLAR MAGNITUDE AT NIGHT.

In order to obtain a result, completely free from prejudice, the following method of observation has been adopted. Using Klein's Star Atlas, a number of fields (mainly in the constellations *Pisces, Orion, Auriga, Gemini, and Camelopardalis*), which contain many stars between the 6th and 7th magnitudes, were compared with the sky on three nights of average good seeing. The observer marked all the stars easily visible with the letter *e,* and those visible with difficulty, that is to say, only after some effort of the eye, with the letter *d.* Of the latter class several faint stars not shown in the Atlas were plotted and looked up later on the charts of the *Bonner Durchmusterung.* In this way two lists of both classes (each containing over 100 stars) were constructed, and only then the magnitudes were taken from the Harvard and Potsdam catalogs. The mean of the 20 faintest magnitudes from each list is considered sufficient for a final statement. In all cases where the B. D. maps showed the possibility of two or three stars being seen as one, the magnitudes of those stars have been corrected with the aid of the table given in *Harvard Annals* **33**, p. 287. Such cases are mentioned in the last columns of Tables III and IV, the differences in brightness of the companions being taken from the B. D. Catalog. For completeness' sake, the spectra (Harvard) and the colors (Potsdam) have been inserted, tho they do not seem to have much bearing on the results. The stars are arranged in the order of their right ascensions.

DISCUSSION OF THE RESULTS.

1. *The transparency curve.* The values of the last column of Table I have been plotted against the apparent magnitudes given in Column 4, and a smooth curve has been drawn thru the points. From this curve the following figures have been read, to which are added the values of the intensity.

TABLE III

STARS EASILY VISIBLE

No.	Star	Harvard	Potsdam	Spectrum	Color	Remarks
1	46 Piscium	$6^{M}.47$	$6^{M}.42$		WG	Comp. $1^{M}.9$ fainter
2	78 "	6 .29	6 .38	A	GW	
3	+23° 150	6 .65	6 .87		W+	
4	+22° 204	6 .25	6 .66		W	Comp. $1^{M}.4$ fainter
5	+16° 154	6 .75	6 .85		GW	
6	+24° 674	6 .27	6 .44	A	W+	
7	95 Tauri	6 .18	6 .39	F	GW—	
8	+23° 739	6 .17	6 .53	A	W+	
9	+24° 709	6 .28	6 .62	F	GW	
10	13 Orionis	6 .26	6 .41	F8	WG	
11	108 Tauri	6 .16	6 .52	A	GW	
12	15 Camelop.	6 .23	6 .42		W	
13	+19° 898	7 .00	7 .02		GW—	
14	+10° 800/801	6 .31	6 .46		GW—	Comp. $2^{M}.0$ f. than 800
15	19 Camelop.	6 .03	6 .40	A	GW	
16	23 "	6 .39	6 .40	K	WG	
17	+60° 915	7 .01	7 .04		GW+	
18	59 Aurigæ	6 .06	6 .38	F	GW	
19	+32° 1460	6 .22	6 .56	F	GW	Comp. $1^{M}.5$ fainter
20	31 Piscium	6 .34	6 .58	A	GW	
	Mean	6 .37	6 .57			

TABLE IV

STARS VISIBLE WITH DIFFICULTY

No.	Star	Harvard	Potsdam	Spectrum	Color	Remarks
1	40 Piscium	$6^{M}.77$	$6^{M}.36$		WG.	
2	+19° 64	6 .57	6 .86		GW—	
3	49 Piscium	6 .94	7 .09		GW	
4	+62° 160	7 .06	7 .06		GW	
5	+20° 139	7 .25	6 .97		G	
6	+24° 163	6 .60	6 .98		GW+	
7	+31° 197	6 .26	7 .04		W+	Comp. $1^{M}.2$ fainter
8	92 Piscium	6 .81	6 .80		GW	
9	+47° 893	7 .16	7 .12	A	WG	
10	+47° 927	7 .31	7 .34		WG	
11	+54° 859	6 .12	7 .03	G	WG+	Comp. $1^{M}.8$ fainter
12	+22° 818	6 .66	7 .04		W+	
13	+ 9° 806	6 .52	6 .90		GW	
14	21 Camelop.	7 .16	7 .16		W+	
15	+63° 599	7 .18	7 .29		WG	
16	+57° 918	7 .18	7 .16		G—	Very difficult
17	+17° 1154	6 .74	7 .49		W+	Comp. $1^{M}.9$ fainter
18	+47° 1299	6 .34	6 .92		W	
19	+28° 1138	6 .76	6 .97		GW	Comp. $2^{M}.7$ fainter
20	+32° 1433	6 .89	7 .22		GW—	
	Mean	6 .81	7 .06			

Magnitude	Intensity	Invisible at Sun's Altitude
3.0	1	— 6°.3
2.0	2.5	— 5 .2
1.0	6.3	— 3 .9
0.0	15.8	— 2 .0
—1.0	39.8	+ 1 .2
—2.0	100	+ 5 .8
—3.0	251	+18 .0

In order to get a "transparency curve," the intensity just visible at any altitude of the Sun should be known; for this purpose *Venus* has been followed thruout the whole interval covered by the observations, but the writer's visit to Mount Wilson had to end before the planet disappeared in the Sun's rays. It was distinctly visible at noon on December 31; the diameter was at that time only 12″, the stellar magnitude —3.4 (Intensity = 363) and the distance from the Sun's limb = 27° In order to represent completely the condition of the atmosphere, therefore, the maximum of the transparency curve must correspond to an intensity somewhere between 251 and 363. If we adopt intensity 300, the curve has the form represented by Fig. 1. The flattening at maximum is a function both

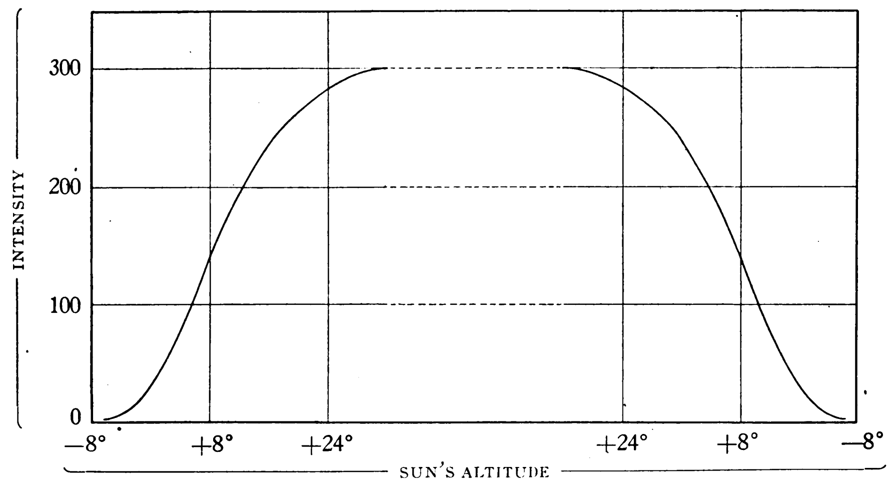

Fig. 1. Transparency Curve.

of the altitude of the observing station (outside our atmosphere the curve would be depressed to the line of abscissæ) and of the condition of the atmosphere. As such it can be compared with similar curves, which may be obtained at other places.

2. *The limiting magnitude at night.* From the mean values, given at the foot of Tables III and IV, we may draw the conclusion that, roughly speaking, under average conditions on Mount Wilson, stars of magnitude $6^{M}.5$ are easily visible, and those of magnitude of $6^{M}.9$ are visible only with some effort of the eye. If we put the limit of visibility at $7^{M}.0$, we are certainly free from exaggeration and we arrive thus at the conclusion that on Mount Wilson the visual limit is about one magnitude or 2.5 times fainter than is usually adopted for stations near sea-level.

Mount Wilson Solar Observatory,
January, 1917.